# Feed-forward error due to the rms fluctuation of the recycling cavities

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Auxiliary degrees of freedom in the interferometer, namely CARM, PRCL, MICH, and SRCL, fluctuate at the level of shot noise in the control bandwidths and couple to DARM via undesirable mixtures of the motions. The mixtures are represented by the off-diagonal terms of the sensing matrix. In fact, the coupling matrix is a product of the sensing matrix and the control matrix, which can also be non-diagonal so that the coupling matrix can be diagonal (or at least the DARM-coupling terms can be zero). The tuning of the control matrix is called *feed-forward* in gravitational-wave detectors.

This shot noise of the auxiliary degrees of freedom appearing on DARM is called loop noise. It is important to design the interferometer control scheme with loop noise sufficiently lower than the sensitivity. While it is quite challenging to realize such a scheme without the feed-forward, the first-generation detectors have already demonstrated the feed-forward gain of 100 or more and KAGRA can also rely on it.

One possible issue on the feed-forward would be the robustness. If the required functions of the control matrix change in time or not so certain, the errors would limit the feed-forward gain and thus the loop-noise level. Here we investigate the error in the feed-forward filter using the simulation code *Optickle*. First we calculate the sensing matrix and derive the ideal feed-forward filter. Second we add 1 % error in the feed-forward filter elements and calculate loop noise. So far it is just a regular procedure that everyone has been doing. After the second step, we save the feed-forward filter functions. We then recalculate the transfer functions with adding errors on the position of the PRM, SRM, and BS. This would give a new ideal feed-forward filters, but now we use the original feed-forward filter functions instead. The results show the loop-noise level with the realistic feed-forward.

Figure 1 shows the loop-noise spectra with $10^{-12}$ m (left) and $10^{-11}$ m (right) error in the position of PRM, SRM, and BS. In the former case the loop-noise level is not so different from the case without an error, but in the latter case loop noise is slightly limiting the sensitivity. Comparing the inspiral range for the neuron-star binaries, one obtains the following table:

| Error | $-10^{-11}$ m | $-10^{-12}$ m | no error | $+10^{-12}$ m | $+10^{-11}$ m |
|---|---|---|---|---|---|
| Inspiral range | 242.26 Mpc | 244.35 Mpc | 244.47 Mpc | 244.56 Mpc | 244.18 Mpc |

The range is not balanced between the positive and negative errors since the feed-forward filter has already a 1 % error from the ideal one.

Our calculation has shown that the position errors of the recycling cavity optics can cause an increase of loop noise and the influence can be non-trivial if the position error is larger than

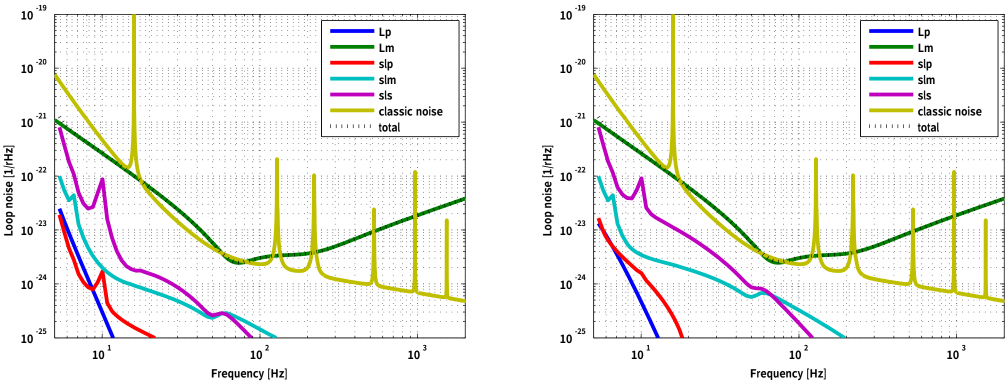


Figure 1: Loop-noise spectra with $10^{-12}$ m (left) and $10^{-11}$ m (right) error in the position of PRM, SRM, and BS.

$10^{-11}$ m. This includes the rms fluctuation of the mirrors. The rms motions of the test masses would be at the level of $10^{-14}$ m (the value for iLIGO), but we should be careful for the rms motion of the recycling mirrors.